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Coupled Bending/Lateral Load Modeling of Earth Penetrators

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COUPLED BENDING/LATERAL LOAD MODELING OF EARTH PENETRATORS

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ABSTRACT

A procedure has been developed to calculate the distributed forces on a penetrator and its motion for an oblique impact with a geological target. Coupling between the lateral forces and bending of the penetrator is accounted for. The penetrator is modeled as a beam of variable stiffness with the general analysis code ABAQUS, and the loading is determined in a DLOAD subroutine that uses previously developed results for the pressure required to expand either a cylindrical or spherical cavity in the target. Results are calculated for a standard Davis Gun penetrator entering antelope tuff at either a 2° angle of attack or a 30° angle of incidence. The lateral acceleration of a Pershing-II penetrator is calculated and compared with data recorded in a field test. The ABAQUS/cavity expansion procedure can be applied to phase 3 penetrator development and testing to predict the trajectory, structural response, and component shock response.

ACKNOWLEDGMENT

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CONTENTS

INTRODUCTION

A procedure has been developed for calculating the lateral loading on an earth penetrator, its bending response, and its trajectory in an oblique penetration event, such as in Figure 1. If either the angle of attack α or the angle of incidence β are nonzero, lateral loads will be generated. The target and penetrator motion will be three-dimensional. One approach is to treat the target/penetrator interaction with a continuum dynamics code such as PRONTO 3D, [1,2].

The present approach couples the lateral loading and penetrator bending. It determines both quantities in one calculation by using the general purpose structural code ABAQUS with a dynamic load (DLOAD) subroutine that specifies the lateral loading via either cylindrical or spherical cavity expansion model theory. A previous benchmark study [6] showed that 1D cavity expansion modeling [7] gives good comparisons with field test measurements for the axial loading on full-scale penetrators into antelope tuff. The nonlinear geometry (NLGEOM) option in the ABAQUS solution procedure is chosen to allow for finite rotations of the structural elements if the penetrator trajectory is highly curved.

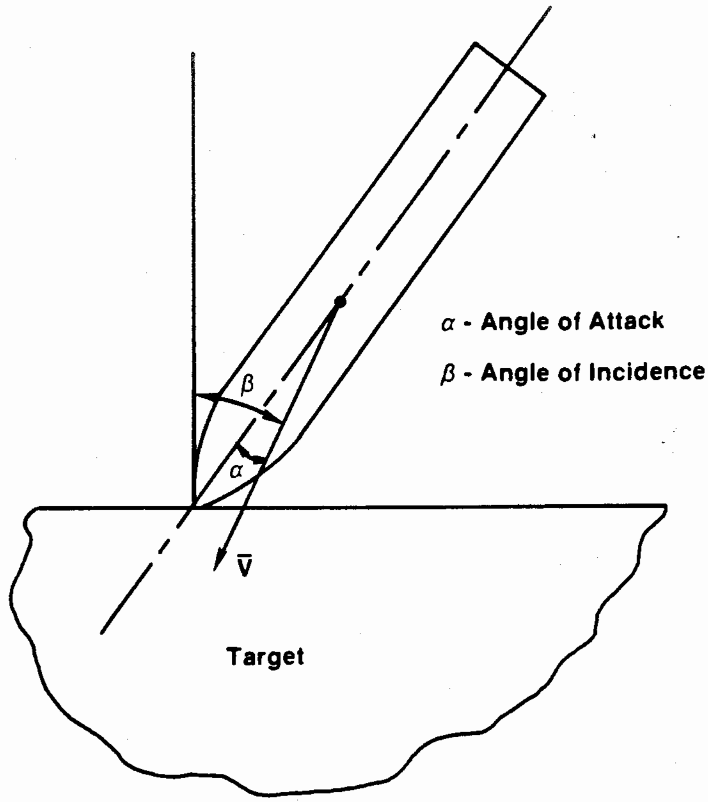

Figure 1. Geometry of an Oblique Impact.

The trajectory, lateral loading, and effect of bending on the lateral loading have been calculated for a typical field test of a standard Davis Gun penetrator impacting antelope tuff

The ABAQUS/cavity expansion procedure can now be applied to phase 3 penetrator development and testing to predict the trajectory, structural response, and component shock environment. The distributed loading determined with this procedure can be used as input to a more detailed penetrator model;

e.g., one which represents the case with shell elements and accounts for circumferential variation of the loading.

ABAQUS STRUCTURAL MODEL OF A PENETRATOR

An ABAQUS structural model that represents lateral bending stiffness of a penetrator with B21 pipe elements is used. This representation of the standard Davis Gun penetrator with a 6.0 CRH (caliber radius head) nose is shown in Figure 2. Parameter values of the structural model are given in Table 1.

Table 1. Parameters of the Structural Model of the Standard Davis Gun Penetrator.

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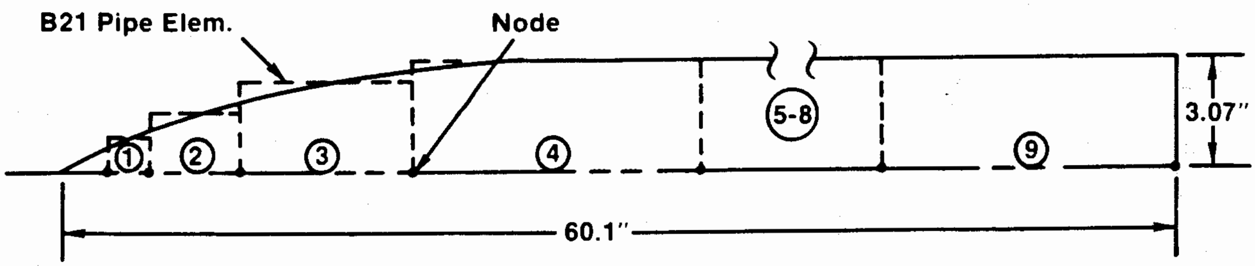

Figure 2. Structural Model of the Standard Davis Gun Penetrator.

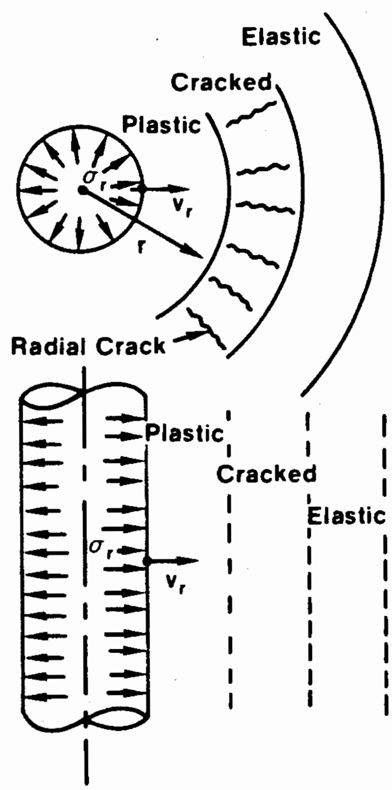

Figure 3. Expanding Cylindrical Cavity and Surrounding Response Regions.

Figure 4. Cylindrical Cavity Expansion Stress in Antelope Tuff.

calculated with the GNOME penetration code and with independent closed-form analysis [8]. Other results of the model verify the required symmetry in angle of attack and in angle of incidence.

RESULTS FOR THE STANDARD DAVIS GUN PENETRATOR

Results were calculated with ABAQUS for a typical test in which the standard Davis Gun penetrator impacted antelope tuff filter frequency. Some uncertainties that could contribute to the difference in calculated and measured acceleration are the angle of attack at impact (it was determined only at rest in the Davis Gun), neglecting frictional effects, the target material properties, and the penetrator structural modeling (for example, in the representation of the mass distribution by artificially high case densities).

CONCLUSIONS

A calculational procedure has been developed that determines the distributed lateral forces on earth penetrators with bending flexibility and their trajectories for oblique impacts. The procedure requires relatively short computation times and is suitable for support of penetrator design and testing. Results for a standard Davis Gun penetrator a

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APPENDIX

Kinematics

The definitions of the coordinate system and vectors that describe the kinematics of the finite elements of a penetrator structural model are shown in Figure 14. The vertical coordinate y is in the direction normal to the target surface, which is assumed planar, and x is the horizontal coordinate. The unit vectors are $\hat{i}$, $\hat{j}$, and $\hat{k} = \hat{i} \times \hat{j}$ in the x, y, and z directions, respectively.

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